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By R.W. Drisko

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COATING GALVANIZED STEEL

ABSTRACT An experiment was conducted to determine the factors that contribute to deterioration of coatings on galvanizing and how to obtain better coating performance. Variables included six surface treatments, two weathering variations, and five chemical compositions. Coating properties measured were initial bonding to galvanizing and salt fog resistance. Significant conclusions were: (1) wash priming improved both bonding strength of coatings to unweathered galvanizing and salt fog resistance of coatings to both weathered and unweathered galvanizing (no other surface treatment was beneficial), (2) weathering of the galvanizing before coating generally reduced bonding but improved salt fog resistance, (3) the epoxy system performed best of all and did not require wash priming for good performance, and (4) the zinc chromate primer improved salt fog resistance of the alkyd system, but the zinc dust/zinc oxide primer did not.

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METRIC CONVERSION FACTORS

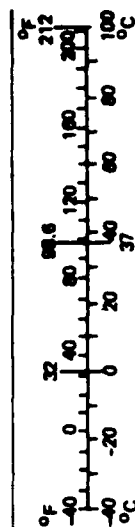
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
VOLUME				
tap	teaspoons	5	milliliters	ml
fl oz	fluid ounces	15	milliliters	ml
c	cups	30	milliliters	ml
pt	pints	0.24	liters	l
qt	quarts	0.47	liters	l
gal	gallons	0.95	liters	l
ft ³	cubic feet	3.8	liters	l
yd ³	cubic yards	0.03	cubic meters	m ³
		0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10.286.

Approximate Conversions from Metric Measures

When You Know	Multiply by	To Find	Symbol
LENGTH			
millimeters	0.04	inches	in
centimeters	0.4	inches	in
meters	3.3	feet	ft
m	1.1	yards	yd
km	0.6	miles	mi
AREA			
square centimeters	0.16	square inches	in ²
square meters	1.2	square yards	yd ²
square kilometers	0.4	square miles	mi ²
hectares (10,000 m ²)	2.5	acres	
MASS (weight)			
grams	0.035	ounces	oz
kilograms	2.2	pounds	lb
tonnes (1,000 kg)	1.1	short tons	
VOLUME			
milliliters	0.03	fluid ounces	fl oz
liters	2.1	pints	pt
liters	1.06	quarts	qt
liters	0.26	gallons	gal
cubic meters	36	cubic feet	ft ³
cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)			
Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

The deterioration of organic coatings on galvanized steel is one of the most commonly encountered problems at Naval shore activities (Ref 1), with disbonding and peeling of coating frequently occurring. The procedure recommended by the Naval Facilities Engineering Command (NAVFAC) for topcoating galvanizing (Ref 2) is not reliable, since it frequently results in early coating failure. Recommended practices by private industry are broad and similarly ineffective, so that necessary guidance is unavailable. As a consequence, NAVFAC has funded the Naval Civil Engineering Laboratory (NCEL) to investigate those factors that are related to early deterioration of coatings on galvanized steel, and methods by which they might be alleviated.

PURPOSE OF INVESTIGATION

The investigation conducted by NCEL was a short-term study of the mechanisms of deterioration of organic coatings on galvanized steel, and the materials and methods that might be utilized to deter these mechanisms. It was not the design or intent of the investigation to develop field recommendations.

BACKGROUND

Zinc Coatings for Steel

There are five types of zinc coating that find use at Naval shore activities today. These will be discussed separately in order to show differences and to define the type of zinc coating investigated by NCEL. The economics of different zinc coating systems, discussed in Reference 3, shows how the initial high cost of zinc coatings is offset by the long period of protection. It also shows how this protection can be further extended by topcoating.

Electrically deposited zinc coatings (electroplated) are very thin, so that they provide very limited protection. They are usually no thicker than 0.2 ounces per square foot of surface area (the units normally used to express thickness of galvanizing). Nevertheless, they are occasionally found at Naval shore activities.

Hot dipped galvanizing provides a much greater thickness and, thus, much longer protection. It is used extensively throughout the Naval shore establishment and is the material that was used in this investigation. Galvanizing forms a continuous barrier that isolates the underlying steel from the water and salts that are necessary for corrosion. The corrosion rate of zinc is less than steel, despite its higher natural electrochemical potential. It is this higher potential that

provides protection to steel exposed by breaks in the barrier film by cathodic (galvanic) protection. The length of protection provided by galvanizing is related directly to its thickness. Commonly, 0.63 to 1.0 ounces per square foot are applied to steel plate. During hot dipping, the zinc forms an alloy at the zinc-steel interface. This is unique among the various types of zinc coatings for steel.

Inorganic zinc coatings are spray-applied coatings with a silicate binder that forms a relatively porous film. They cannot initially provide barrier protection, but protect steel by cathodic protection. As the zinc sacrifices itself cathodically, its corrosion products fill the pores so that a barrier film is gradually formed. Because these coatings are quite inflexible, they must be relatively thin (usually applied at about 3 mils dry film thickness) in order to avoid mud cracking.

Organic zinc coatings (inorganic and organic zinc coatings are frequently grouped as zinc-rich coatings) contain organic binders (e.g., epoxy or vinyl) and form impervious films that can provide barrier as well as cathodic protection. These coatings are also applied very thinly (e.g., 3 mils dry film thickness).

Thermal sprayed, usually flamesprayed, coatings (metallizing) can be built up to relatively high film thicknesses of zinc or aluminum metal. The film is porous, so that it is usually topcoated with a sealer for longer life. Such coatings are used extensively on components of Navy ships. Aluminum is much more widely used on ships than zinc because of health and safety hazards, as described in Military Standard DOD-STD-2138 (SH) (Ref 4).

Topcoating of Galvanizing

It has been stated by an authority on galvanizing (Ref 5), "It is well known that smooth, freshly galvanized surfaces are difficult to coat with paints generally used on steel, as poor adhesion may result after a time." Attempts at improving the bonding of topcoats to smooth galvanizing have lead to such practices as washing with vinegar, washing with copper sulfate solution, or weathering before topcoating. These practices are still in use today. Roebuck et al. (Ref 3), state that hot dipped galvanizing should be weathered or treated with an activator such as wash primer or phosphoric acid to slightly etch the surface before topcoating. A few papers have been written on topcoating of galvanizing (Ref 5 and 6), but they only list different systems that are available without specifying the best system or systems. They do not specify the pretreatment of the galvanizing that is most likely to provide best performance in conjunction with a particular coating system.

NAVFAC (Ref 2) recommends the use of TT-P-641, with or without pretreatment, as a primer for galvanizing. TT-P-641 is a specification covering linseed oil, alkyd, or phenolic drying oil products with a zinc dust-zinc oxide pigmentation. Roebuck et al. (Ref 3), state "For instance, coatings subject to saponification (e.g., alkyds) are not recommended as topcoats for metallic zinc coatings." Berger (Ref 7) concurs that this action leads to disbonding and loss of coating. All three types of TT-P-641 are subject to saponification, since they contain drying oils. The General Services Administration (GSA) sells considerable quantities of TT-P-641, Type I (linseed oil type) and Type II

(alkyd type), but no Type III (Ref 8). In 1984, they sold about twice as much Type I as II, but in 1987, they sold about the same quantities of Type I and Type II. GSA also sells MIL-E-15145, mostly for the interior of fresh water tanks, this coating is similar chemically to Type III. Types I and II are sold mostly for use on new or weathered galvanizing. No TT-P-641 type provides cathodic protection, so that only barrier protection is possible (Ref 7).

Many proprietary coatings are currently available for coating galvanized steel. Epoxy and latex coatings are particularly popular. This is a strange combination, because epoxies are very impervious and latex coatings relatively pervious (breathing) coatings. In most cases, the supplier did not base his coating formulation on a scientific principle, but rather on trial and error, or past knowledge or beliefs.

From the above discussion, it is apparent that there is neither reliable guidance for our field activities, nor a real understanding of the actual causes of observed failures or methods of protection. From the number of field problems encountered, it seems that this basic information and subsequent guidance based on it would be very valuable to Navy field activities.

Mechanisms of Coating Failure

Several possible mechanisms for failure of organic coatings on galvanizing have been proposed:

- Poor bonding of coating to new galvanizing (because of the smooth, bright, spangled surface of the galvanizing or because of factory preservative treatments)
- Deterioration of initially acceptable bonding by moisture penetration of coating (effect of wet adhesion)
- Underfilm corrosion (undercutting) of the zinc surface accelerated by moisture penetration
- Chemical degradation of coatings, particularly saponification of alkyd coatings in an alkaline environment
- Differences in expansion and contraction of metal and coating
- Impurities on the surface of the galvanizing
- A combination of the above

The difficulty in bonding to the smooth surface of galvanizing has resulted in the development of the many methods that have been used to texture it. Some people (Ref 6) caution against the use of special treatments other than weathering: "The 'home cure' type of treatments such as washing the surface with vinegar, acetic acid, cider, copper sulfate solution, muriatic acid, or hydrochloric acid have been proved to be useless, or even harmful."

A bulky white or gray deposit (wet storage stain) may form on the surface of the galvanizing, particularly if moisture is present between stored sheets of galvanizing (Ref 6, 9, and 10). This deposit is a mixture of alkaline zinc corrosion products which may impart serious adverse effects to the galvanizing. Thus, most producers of galvanized sheets apply an inhibitor for temporary protection from wet stain storage (Ref 5, 6, and 11). The inhibitive treatment may be chemical (e.g., chromate) or oiling (Ref 12). Some of these treatments (particularly oiling) may inhibit bonding of paint and, thus, should be removed before coating.

No organic coating (only continuous metallic coatings) is completely impervious to moisture. Moisture on the metal-coating interface will reduce the coating adhesion. Even on subsequent drying, the original adhesion is not fully restored. Cyclic wetting and drying may result in significant permanent loss of adhesion. Organic coatings vary greatly in their moisture resistance, and thus, in their susceptibility to this type of adhesion loss.

Once corrosion has been initiated under a coating, it may disbond the adjacent coating by underfilm corrosion. Cathodic protection in the presence of conductive moisture would minimize this action.

The corrosion products of galvanizing are chemically alkaline and will degrade coatings that are not alkali-resistant. Oil-based coatings (e.g. the linseed oil, alkyd, and phenolic types of TT-P-641 and epoxy esters) do not have such resistance but still are recommended by NAVFAC or others, with or without a thin coat of wash primer, for galvanizing. Latex coatings are usually formulated for alkali resistance, and epoxy coatings have good alkali resistance. Wash priming is not recommended by suppliers of these latter products.

Organic coatings vary widely in their elongation and thus their ability to expand and contract with the metal to which they are bonded. Generally, latex coatings have a high elongation, and epoxies a very low one. Alkyd and epoxy ester coating elongation varies greatly with the drying oil content (oil length).

Impurities are always present in galvanizing baths. These impurities tend to segregate at spangle edges (grain boundaries) where they may accelerate corrosion of zinc. The presence of magnesium or lead on the surface of galvanizing has been reported (Ref 13) to have possible adverse effects on the bonding of coatings. Other adverse effects may also occur that are not presently understood.

EXPERIMENTAL

Design of Experiments

The experimental design was an analysis of variants believed to be related to coating performance that also included some new approaches to control of corrosion and coating deterioration.

Pretreatment Variations

The surface pretreatment variations investigated are shown below with reported beneficial properties imparted:

<u>Surface Pretreatment</u>	<u>Reported Beneficial Property</u>	
	<u>Adhesion</u>	<u>Corrosion</u>
1. Cobalt treatment		X
2. Chromate treatment		X
3. Phosphoric acid etch	X	
4. Wash primer	X	X
5. Weathering	X	
6. No treatment		

The coating systems used were selected to include different variations of beneficial coating properties:

<u>Coating System</u>	<u>Water Res.</u>	<u>Beneficial Property</u>		
		<u>Corrosion</u>	<u>Alkali Res.</u>	<u>Elong.</u>
A. Alkyd A	X	X		
B. Alkyd B	X			
C. Epoxy Ester	X	X		
D. Latex A			X	X
E. Latex B			X	X
F. Latex C	X		X	X
G. Epoxy	X		X	

Alkyds provide relatively good water resistance, but only fair elongation, and no alkali resistance. Alkyd A had corrosion resistance imparted by zinc chromate inhibitive pigment, but Alkyd B did not.

Epoxy esters are, like alkyds, modified drying oil paints that incorporate some of the features of drying oil (wetability) and epoxy (increased durability) resins. While not nearly as durable as the two-component epoxies, they are considerably cheaper. The particular epoxy ester used had two special features; it contained corrosion inhibitive pigments (zinc molybdate and barium metaborate) and phosphoric acid for better adhesion to galvanizing. Zinc molybdate and barium metaborate are environmentally acceptable alternative corrosion inhibiting pigments to zinc chromate (i.e., are chromate free).

Latex paints have excellent elongation and are usually formulated for alkali resistance. They are of special interest due to their increased use because of environmental concerns. Latex C contained 316 flake stainless steel which would increase its water resistance.

Two-component epoxy coatings have excellent water and alkali resistance, but relatively little flexibility. The epoxy used did not contain an inhibitive pigment, but its polyamide catalyst is believed to have some corrosion inhibitive properties.

The variation of weathering was taken into account by performing similar experiments on weathered and unweathered panels. The experimental design for separate testing of weathered and unweathered panels can be summarized as shown:

Coating System	Surface Treatments				
	1	2	3	4	5
A					
B					
C					
D					
E					
F					
G					

Galvanized Panels

The 3- by 6-inch test panels were cut from sheets of hot-dipped galvanized steel of Commercial Quality, ASTM A 526, Designation G 90, untreated, containing a total of 0.9 ounces per square foot on both sides (0.77 mils on each side). After weathering for 6 months to a marine atmospheric exposure at a beach site at Port Hueneme, California, the thickness of the zinc coating had increased slightly from corrosion products (wet storage stain). A scanning electron microscope analysis of the initial surface showed only small particles of lead contamination and traces of silicon and aluminum in addition to the zinc.

Surface Treatments

In all treatments described below, the panels were first solvent degreased by immersion in methylethyl ketone before treatment. The weathered panels were lightly washed with water using a soft brush followed by rinsing with demineralized water to remove loose corrosion products that might deter coating adhesion.

The cobalt and chromate treatments were systems based on the work of Leidheiser et al. (Ref 14, 15, and 16), who found that the corrosion of zinc in neutral salt solution is inhibited by certain concentrations of cobalt and nickel. Electrochemical studies at NCEL suggested that such "doping" with cobalt and chromium were more effective than nickel treatment.

The cobalt treatment was accomplished by abrasive polishing with 600-grit silicon carbide paper and aluminum oxide, rinsing with water, immersing 30 seconds in 0.05 M (molar) cobalt chloride solution, and rinsing with water. The chromate treatment was accomplished by immersing 1 minute in phosphoric acid solution (see paragraph below), rinsing

and drying, immersing 20 minutes in chromate/nitrate solution (4.5 g. calcium nitrate and 1.6 g. potassium chromate in 1 liter of water), and rinsing with water.

The phosphoric acid treatment is one used extensively in private industry (Ref 17). It is chemically similar to the acid component of wash primer MIL-P-15328, and it consists of a solution of 11.16 parts by volume phosphoric acid, 15.22 parts water, and 76.15 parts isopropyl alcohol.

The wash primer used was MIL-P-15328 (Formula 117). It is spray-applied to give 0.3- to 0.5-mil dry film thickness and is used on ships to improve the adhesion of vinyl coatings.

Coating Systems

Alkyd System A consisted of one coat of an alkyd primer (TT-P-645) and two alkyd topcoats (TT-E-489). This primer, with zinc chromate as a corrosion inhibitive pigment is used extensively and very effectively on steel, but not galvanizing.

Alkyd System B consisted of one coat of an alkyd primer (TT-P-641) Type II and two alkyd topcoats (TT-E-489). The pigment in this primer does not provide cathodic protection. The primer is used extensively on galvanizing, but not steel.

The epoxy ester system consisted of two coats of a proprietary epoxy ester containing corrosion inhibitive pigments and phosphoric acid.

Latex A consisted of two coats of a modification of TT-P-19 formulated by the Air Force Engineering and Services Center and the National Bureau of Standards (Ref 18). It is reported to have superior properties to unmodified TT-P-19.

Latex System B consisted of two coats of a proprietary latex paint. It was considered to be one of the better proprietary latex products available.

Latex System C consisted of two coats of a proprietary latex paint that contains 31% flake stainless steel. It has a record of good performance on galvanizing.

The epoxy system consisted of two coats of epoxy-polyamide MIL-P-24441 (Formula 150 primer and Formula 152 topcoat). It has a record of long and successful use by the Navy.

All coating systems tested were spray applied in accordance with their specification or manufacturer's recommendation.

The dry film thicknesses of these systems applied to test panels are listed in Table 1. They were determined by magnetic gage.

Experimental Procedure

For each variation in the experimental design, four specimens were prepared. Two specimens of each set were used to determine the adhesion of the coatings to the galvanizing before exposure. One of the remaining specimens of each set was mechanically scribed with an "X" extending most of the diagonal length of each panel through the coating to expose the steel beneath the galvanizing. A scribed and unscribed panel from each set was placed in a 5 percent salt fog exposure chamber, and the conditions of the coatings and galvanizing were rated periodically.

Six adhesion measurements were made on each of the two test specimens of each set prepared for this purpose and the values averaged. In the test procedure, dumbbell-shaped steel probes having an abrasively blasted flat base with an area of 1.00 cm² were bonded onto the topcoat with an epoxy adhesive (Hysol EA9309). After curing of the adhesive for 3 days, the adhesive was cut with a razor around each probe. The probes were then pulled from the specimen using a table model Instron testing machine at a rate of 0.5 cm/min. Replicate measurements were quite close. Adhesion measurements were also planned for test specimens after salt fog testing, but many of the specimens were too severely damaged for meaningful measurements.

Salt fog testing was selected in order to achieve fairly early results of coating performance. It was realized that the results could not be extrapolated into months of field performance, but it was believed to be satisfactory for drawing conclusions in the analysis of the variants used in the experiments. The panels were exposed in a commercial salt fog chamber with 5 percent salt solution used. Ratings were recorded on a scale of 1 to 10 to the nearest half unit. They were done after one week of exposure and at least monthly thereafter. Standard ASTM ratings for coating deterioration (i.e., blistering and peeling) and steel corrosion were weighted to give an overall rating of general protection. The ratings can be expressed simply: 10 is perfect; 9 is good; 8 is fair; and 7 is failure. Systems were no longer rated after receiving a rating of 7.

RESULTS

The average values of initial adhesion for each test variation are listed in Table 2 for the unweathered and weathered galvanized specimens. For comparisons of salt fog resistances, the ratings for weathered and unweathered specimens for general protection were tabulated as described below:

<u>Table Number</u>	<u>Weathered or Not</u>	<u>Scribed or Unscribed</u>	<u>Days Salt Fog Exposure</u>
3	Unweathered	Unscribed	139
3	Unweathered	Scribed	139
4	Unweathered	Unscribed	198
4	Unweathered	Scribed	198
6	Weathered	Unscribed	241
6	Weathered	Scribed	241
7	Weathered	Unscribed	314
7	Weathered	Scribed	314

The particular exposure times were chosen because they showed a good range of values. Salt fog resistance data were also tabulated in terms of days to initial failure as described below:

<u>Table</u>	<u>Weathered or Not</u>	<u>Scribed or Unscribed</u>
5	Unweathered	Unscribed
5	Unweathered	Scribed
8	Weathered	Unscribed
8	Weathered	Scribed

DISCUSSION OF RESULTS

Effects of Surface Treatments

The most obvious finding in the investigation is that the use of wash primer on unweathered galvanizing greatly increases both the adhesion of the primers of each coating system and the system's salt fog resistance. A notable exception to this trend was the epoxy system that received improved adhesion but had excellent salt fog resistance, with or without the wash primer. The effects of other treatments on unweathered galvanizing was variable but slightly improved adhesion on the average. From Tables 3, 4, and 5, it can be seen that the other surface treatments did not improve salt fog resistance. Indeed, phosphoric acid treatment slightly decreased overall performance. This was due to its very adverse effect on Latex C, which in turn, may have been caused by reaction of the acid treated surface with the stainless steel in this material.

The different surface treatments had much less effect on the adhesion of the coatings to the weathered than on the unweathered galvanizing. The slightly greater adhesion to wash-primed weathered surfaces is associated with better bonding of the latex systems. It can be seen from Tables 6, 7, and 8 that with two exceptions, coating systems performed as well on wash primed surfaces as on other surface treatments. The statistical significance was much less than on the unweathered panels, because of the much better overall performance on the weathered galvanized panels. The adverse effect of phosphoric acid on Latex C noted above did not occur with the weathered galvanized specimens. The lack of benefit on chromate treatment is supported by data from a previous investigation (Ref 19) and the recommendations of the Galvanizers Association of Australia (Ref 20). Nevertheless, many paint suppliers and consultants recommend chromate pretreatments for specific coatings.

Effects of Weathering Galvanizing

Weathering of the galvanizing greatly decreased the bonding strength of the primers, as seen in Table 2. A notable exception was the zinc chromate primer of Alkyd System A that exhibited extremely poor adhesion

on all surface treatments of unweathered galvanizing, except wash priming. Salt fog testing showed an opposite trend; coating systems performed much better on the weathered than the unweathered panels. This can be seen by comparing Tables 3, 4, and 5, to Tables 6, 7, and 8, respectively. From data in these tables and Table 2, it can be concluded that corrosion of the galvanizing with formation of zinc corrosion products during weathering, significantly reduced overall bonding of primers and significantly increased salt fog resistance. Zinc corrosion products or other contaminants on the surfaces of the weathered galvanizing may have significantly reduced adhesion, but had a lesser effect on salt fog performance.

Although weathering of galvanizing before painting has long been advocated by many people as a means of improving paint performance, it is by no means a universally accepted practice. A report of the Iron and Steel Institute shows only marginal improvement. The improvement found in the present salt spray study may offset, in part, any surface contaminants picked up during weathering that are not removed by cursory cleaning.

Effects of Adhesion on Salt Fog Resistance

Data on bonding strengths correlated poorly with salt spray performance. On unweathered galvanizing, the epoxy system had the best overall adhesion and the best salt fog resistance. However, there was a great fluctuation in bonding strength with different treatments, and all epoxy specimens performed very well. There was a relatively small range of bonding strengths for the different coating systems on weathered galvanizing, but there was a much greater variation in salt fog performance. In addition, latex systems bonded much better overall than the oil-based systems (i.e., alkyd and epoxy ester) but did not perform better than Alkyd A or the epoxy ester.

Effects of Coating Composition/Properties

Although the study was not intended to be an evaluation of coatings, the experimental design was prepared to elicit information on effects of various properties associated with different formulations. Salt fog results for both weathered and unweathered specimens showed four definite levels of performance.

The epoxy system performed in a class by itself, continuously receiving perfect ratings. This is attributed to its excellent adhesion and water resistance. Its limited flexibility did not seem to detract from its performance. It should be noted that epoxies chalk relatively freely during exterior exposure, but this would be expected to have only little effect on protection of galvanizing.

The second best level of performance for both series included the zinc chromate alkyd (Alkyd A) and the epoxy ester. Their salt fog ratings were almost as good as that of the epoxy on the weathered panels (Tables 6 and 7), but significantly less on the unweathered panels (Tables 3 and 4). Indeed, on the unweathered panels the epoxy ester ratings were just above those of the latex systems. Obviously, the zinc chromate pigment of the Alkyd A primer resulted in greater performance than did the zinc dust-zinc oxide pigment in the Alkyd B primer. Also,

the barium metaborate pigment in the epoxy ester primer did not improve salt fog resistance of this system to the extent that the zinc chromate pigment did to Alkyd A. The phosphoric acid in the epoxy ester primer did not improve adhesion or salt fog performance of the epoxy ester system.

The three latex systems constituted the third level of performance. Their performances were quite similar overall. Latex C performed slightly better than the other two latexes on the weathered panels. It would have performed better overall on the unweathered panels except for its poor performances with phosphoric acid treatment. The differences in salt fog resistance of Latex C are probably due to the 316 flake stainless steel it contains. It should be noted that salt fog exposure is more severe to latex than other generic coatings, so that they may perform much better relative to the other test coatings in a natural environment.

Alkyd B had the worst salt fog resistance. This can best be seen from its times to failure in Tables 5 and 8. Its reported good performance based upon its zinc dust-zinc oxide primer was not in evidence.

Effects of Film Thickness

Little correlation was noted between thicknesses of the coating systems and adhesion or salt spray performance. On the other hand, it is known that film thickness affects performance in several ways. Within limits, a higher film thickness will provide greater barrier protection by retarding the permeation of water, ions, and oxygen. An excessively thick film, however, may be brittle and mudcrack or disbond under stresses from hot/cold cycling. The differences in thickness of the various systems in Table 1 are related to the natural film build of each system. Thus, Latex C, which is filled with stainless steel, had a greater build than Latexes A and B.

NEW HEALTH/ENVIRONMENTAL CONCERNS

There is now an increased concern about possible health and environmental hazards associated with paint components. Chief among these concerns are the VOCs in solvents and thinners and lead and chromate pigments. Presently, only the latex systems used in this test meet VOC requirements for architectural coatings, although the epoxy system is being reformulated to meet them. Alkyd A and wash primer contain chromate, and so their use soon may be restricted. Thus, many of the options used in this test program may soon become unavailable.

CONCLUSIONS

The major conclusions of the investigation are as follows:

- Wash primer provided significant improvement bonding strength of coatings systems to unweathered galvanizing and improved salt fog resistance of coating systems on both weathered and unweathered galvanizing.

- None of the other surface treatments investigated proved to be beneficial.
- Weathering of the galvanizing prior to coating usually reduced bonding of the primer but significantly improved salt resistance.
- The epoxy system performed best of all and did not require wash priming for excellent salt fog performance on weathered or unweathered galvanizing.
- The incorporation of zinc chromate in Alkyd A greatly improved its salt fog resistance.
- The presence of zinc dust-zinc oxide pigment in Alkyd B did not improve its salt fog performance, and it performed worst of all.

RECOMMENDATIONS

It is recommended that the coating systems used in the described investigation be field tested, along with environmentally acceptable systems, on galvanized steel to determine whether the effects of salt-fog exposure are duplicated by natural exposure.

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Table 1. Thickness of Coatings on Untreated Specimens (mils)

Weathered				
Coating System	1st Coat	2nd Coat	3rd Coat	Total
Alkyd A	0.9	0.7	1.1	2.7
Alkyd B	1.5	1.2	0.8	3.5
Epoxy Ester	2.1	2.2		4.3
Latex A	2.1	2.1		4.2
Latex B		1.9	2.4	4.3
Latex C	5.2	2.6		7.8
Epoxy		1.8	3.2	5.0
Weathered				
Alkyd A	0.9	0.6	0.9	2.4
Alkyd B	1.0	0.6	1.0	2.6
Epoxy Ester	2.0	2.6		4.6
Latex A	2.3	2.3		4.6
Latex B	1.7	2.8		4.5
Latex C	4.0	3.6		7.6
Epoxy	3.8	3.9		7.7

Table 2. Bonding Strengths (Kg/cm^2) to Galvanizing

Coating System	Surface Treatment					Average
	Cobalt Treatment	Chromate Treatment	Phosphoric Acid	Wash Primer	None	
Unweathered						
Alkyd A	11	3	3	47	2	13
Alkyd B	30	28	25	30	25	28
Epoxy Ester	20	49	43	39	28	36
Latex A	70	46	47	69	23	51
Latex B	36	41	33	39	39	38
Latex C	46	31	39	59	11	37
Epoxy	44	38	66	79	61	58
Average	36.7	33.7	36.6	51.7	27.0	
Weathered						
Alkyd A	14	15	16	14	16	15
Alkyd B	15	14	13	12	13	13
Epoxy Ester	15	12	13	15	14	14
Latex A	15	15	14	21	20	17
Latex B	12	10	11	17	13	13
Latex C	29	12	14	29	20	21
Epoxy	14	11	16	17	11	14
Average	16.3	12.7	13.9	17.9	15.3	

Table 3. Performance of Coating on Unweathered Galvanizing
After 139 Days Salt Fog Exposure*

Coating System	Surface Treatment					Average
	Cobalt Treatment	Chromate Treatment	Phosphoric Acid	Wash Primer	None	
Unscribed						
Alkyd A	9.5	9	9	10	8	9.1
Alkyd B	7 (47)	7 (47)	7 (47)	8	7 (47)	7.2
Epoxy Ester	9	8.5	8.5	9.5	8.5	8.8
Latex A	8.5	9.5	8	10	8	8.8
Latex B	8	8	7.5	9	8.5	8.2
Latex C	8	8	7 (47)	9	8.5	8.1
Epoxy	10	10	10	10	10	10
Average	8.6	8.6	8.1	9.4	8.4	
Scribed						
Alkyd A	9.5	9	9	9.5	8.5	9.1
Alkyd B	7 (33)	7 (63)	7 (33)	8	7 (47)	7.5
Epoxy Ester	9	8.5	8.5	9.5	8	8.7
Latex A	8	8	8	9	8	8.2
Latex B	7.5	8	8	9	9	8.3
Latex C	8	8	7 (33)	8.5	8	7.9
Epoxy	10	10	10	10	10	10
Average	8.4	8.4	8.2	9.1	8.4	

*10 = perfect; 9 = good; 8 = fair; 7 = failure
Figure in () is days to failure.

Table 4. Performance of Coating on Unweathered Galvanizing
After 198 Days Salt Fog Exposure*

Coating System	Surface Treatment					Average
	Cobalt Treatment	Chromate Treatment	Phosphoric Acid	Wash Primer	None	
Unscribed						
Alkyd A	9	9	8.5	9.5	9	9.0
Alkyd B	7 (47)	7 (47)	7 (33)	8	7 (47)	7.2
Epoxy Ester	8	8	8	10	8	8.4
Latex A	8	8	7.5	10	7.5	8.2
Latex B	7.5	7.5	8	10	8	8.2
Latex C	8	8	7 (47)	9	8	8.0
Epoxy	10	10	10	10	10	10
Average	8.2	8.2	8.0	9.5	8.2	
Scribed						
Alkyd A	9	9	8.5	9.5	9	9.0
Alkyd B	7 (33)	7 (63)	7 (33)	7.5	7 (47)	7.1
Epoxy Ester	8	8	8	10	8	8.4
Latex A	7.5	7.5	7 (198)	9.5	7.5	7.8
Latex B	7.5	8	7.5	9.5	8	8.1
Latex C	8.5	8	7 (33)	9	8	8.1
Epoxy	10	10	10	10	10	10
Average	8.2	8.2	7.9	9.3	8.3	

*10 = perfect; 9 = good; 8 = fair; 7 = failure
Figure in () is days to failure.

Table 5. Days to Salt Spray Failure For Coating on Unweathered Panels*

Coating System	Surface Treatment					Average
	Cobalt Treatment	Chromate Treatment	Phosphoric Acid	Wash Primer	None	
Unscribed						
Alkyd A	431	431	282	>431	348	>385
Alkyd B	47	47	33	282	47	91
Epoxy Ester	282	282	282	>431	282	>312
Latex A	282	282	233	>431	233	>292
Latex B	282	282	348	>431	282	>325
Latex C	>431	431	47	>431	348	>378
Epoxy	>431	>431	>431	>431	>431	>431
Average	>312	>312	>237	>410	>282	
Scribed						
Alkyd A	431	348	348	>431	>431	>398
Alkyd B	33	63	33	282	47	92
Epoxy Ester	282	282	282	>431	282	>312
Latex A	282	233	198	>431	233	>275
Latex B	282	282	282	>431	282	>312
Latex C	431	282	33	>431	282	>292
Epoxy	>431	>431	>431	>431	>431	>431
Average	>310	>274	>230	>431	>284	

*Salt spray exposure terminated after 431 days

Table 6. Performance of Coating on Weathered Galvanizing
After 241 Days Salt Fog Exposure*

Coating System	Surface Treatment					Average
	Cobalt Treatment	Chromate Treatment	Phosphoric Acid	Wash Primer	None	
Unscribed						
Alkyd A	10	10	9.5	10	10	9.9
Alkyd B	7 (175)	7 (241)	7 (241)	8.5	7 (47)	7.3
Epoxy Ester	9.5	10	10	10	10	9.9
Latex A	7 (175)	7 (241)	7 (175)	10	7.5	7.7
Latex B	7 (241)	7.5	8	10	8	8.1
Latex C	7 (241)	10	7.5	10	8	8.5
Epoxy	10	10	10	10	10	10
Average	8.2	8.8	8.4	9.8	8.6	
Scribed						
Alkyd A	9.5	10	10	10	9.5	9.8
Alkyd B	7.5	7 (175)	7.5	9	7 (7.5)	7.6
Epoxy Ester	10	9.5	9.5	10	9.5	9.7
Latex A	7.5	7.5	7.5	10	7 (241)	7.9
Latex B	8	7.5	7.5	9.5	7.5	8.0
Latex C	8	8	8	9	8.5	8.3
Epoxy	10	10	10	10	10	10
Average	8.6	8.5	8.6	9.6	8.4	

*10 = perfect; 9 = good; 8 = fair; 7 = failure
Figure in () is days to failure.

Table 7. Performance of Coating on Weathered Galvanizing
After 314 Days Salt Fog Exposure*

Coating System	Surface Treatment					Average
	Cobalt Treatment	Chromate Treatment	Phosphoric Acid	Wash Primer	None	
Unscribed						
Alkyd A	10	10	8.5	10	10	9.7
Alkyd B	7 (175)	7 (241)	7 (241)	9	7 (175)	7.4
Epoxy Ester	9.5	10	10	10	10	9.9
Latex A	7 (175)	7 (241)	7 (175)	8.5	7 (314)	7.3
Latex B	7 (314)	7 (314)	7 (314)	8	7 (314)	7.2
Latex C	7 (241)	10	8	9.5	7 (314)	8.3
Epoxy	10	10	10	10	10`	10
Average	8.2	8.7	8.2	9.3	8.3	
Scribed						
Alkyd A	9.5	9	10	10	9	9.5
Alkyd B	7 (314)	7 (175)	7 (314)	9	7 (175)	7.4
Epoxy Ester	9	10	10	9.5	10	9.7
Latex A	7 (314)	7 (314)	7 (314)	9	7 (124)	7.4
Latex B	7.5	7 (314)	7 (314)	8.5	7 (314)	7.4
Latex C	7.5	8	7.5	9	8	8.0
Epoxy	10	9.5	10	10	10	9.9
Average	8.2	8.2	8.4	9.3	8.3	

*10 = perfect; 9 = good; 8 = fair; 7 = failure

Figure in () is days to failure.

Table 8. Days to Salt Spray Failure For Coating on Weathered Panels*

Coating System	Surface Treatment					Average
	Cobalt Treatment	Chromate Treatment	Phosphoric Acid	Wash Primer	None	
Unscribed						
Alkyd A	>314	>314	>314	>314	>314	>314
Alkyd B	175	241	241	>314	175	>229
Epoxy Ester	>314	>314	>314	>314	>314	>314
Latex A	175	241	175	>314	314	>244
Latex B	314	314	314	>314	314	>314
Latex C	241	>314	>314	>314	314	>299
Epoxy	>314	>314	>314	>314	>314	>314
Average	>264	>293	>284	>314	>294	
Scribed						
Alkyd A	>314	>314	>314	>314	>314	>314
Alkyd B	314	175	314	>314	175	>258
Epoxy Ester	>314	>314	>314	>314	>314	>314
Latex A	314	314	314	>314	241	>299
Latex B	>314	314	314	>314	314	>314
Latex C	>314	>314	>314	>314	314	>314
Epoxy	>314	>314	>314	>314	>314	>314
Average	>314	>294	>314	>314	>284	

*Salt spray exposure terminated after 314 days

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R. N. STORER, Ph.D, P.E.
Technical Director

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SA Strongly Agree A Agree O Neutral D Disagree SD Strongly Disagree

	SA	A	N	D	SD		SA	A	N	D	SD
1. The technical quality of the report is comparable to most of my other sources of technical information.	()	()	()	()	()	6. The conclusions and recommendations are clear and directly supported by the contents of the report.	()	()	()	()	()
2. The report will make significant improvements in the cost and or performance of my operation.	()	()	()	()	()	7. The graphics, tables, and photographs are well done.	()	()	()	()	()
3. The report acknowledges related work accomplished by others.	()	()	()	()	()						
4. The report is well formatted.	()	()	()	()	()						
5. The report is clearly written.	()	()	()	()	()						

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